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RESEARCH ARTICLE

Integrated mapping of ecosystems and assessment of forest ecosystem services at river basin scale

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Abstract

Ecosystems provide various goods and services to society and their valuation is among the main objectives of the concept of ecosystem services (ES). The mapping of ecosystems is the main building block of the whole process of the Mapping and Assessment of Ecosystems and their Services (MAES). The analyses of the ecosystem data produced during the implementation of the national methodology for mapping ecosystems in Bulgaria (MAES BG) reveal some problems that may cause confusion in cases of integrated assessment of all ecosystem types. In this paper, we present an approach that enables formulation of a uniform spatial dataset based on the mapping of the main ecosystem types, that can be used for mapping of ES at a river basin scale. It has been applied to the upper part of the Ogosta River basin and the result is a topologically correct uniform spatial data layer. The approach gives one possible solution to problems related to the different sources of information and the discrepancies between ecosystem types in the national mapping of ecosystems in Bulgaria. It is based on the use of a uniform spatial framework that outlines the ecosystem types and sets the initial database for further mapping. This ensures a topologically correct spatial dataset for the ecosystems and a background for further updates for each ecosystem at the different levels of MAES typology. The most appropriate spatial basis for the territory of Bulgaria is the database for the physical blocks of the Ministry of Interior. Its application to the studied river basin gives encouraging results and can be used as an example for similar areas. Further development of the approach will ensure the mapping of the forest ecosystems at level 3 of the MAES BG typology and more precise delineation of the grassland, heathland, freshwater, and sparsely vegetated ecosystems.

Keywords
CLC, ESA WorldCover, GIS database, MAES typology, physical blocks

Introduction

Ecosystems provide various goods and services to society, which in turn directly contribute to human well-being and various economic activities (Costanza et al., 1997; MA, 2005). Valuing such contributions is among the main objectives of the concept of ecosystem services (ES) which are defined as "the contributions of ecosystem structure and function–in combination with other inputs–to human well-being" (Burkhard et al., 2012). They also have the potential to solve problems related to the conservation of biodiversity and contribute to the achievement of the sustainable development goals (SDG). However, regions whose conservation benefits both biodiversity and ES, cannot be identified unless ES can be quantified and valued and their areas of production mapped (Naidoo et al., 2008). Therefore, the mapping of ecosystems is the necessary basis for further valuation and assessment of ES. This is emphasized also in the European biodiversity strategy with the target mapping of ecosystems and their assessment. This was the driving force for the formation of the Mapping and Assessment of Ecosystems and their Services (MAES) working group that is set to support the implementation of Action 5 by the European Union and its member states.

The MAES working group developed the methodological framework for mapping ecosystems and the services they provide at a European level (Erhard et al. 2016; Maes et al., 2013, 2014, 2020). It has been used as a basis to develop the methodology for Bulgaria under the Methodological assistance for ecosystems assessment and biophysical valuation (MetEcosMap) project. It includes nine separate methodologies, each of which covers a specific ecosystem type according to the MAES typology (Bratanova-Doncheva et al., 2017). In the follow-up mapping, nine separate databases were developed for each ecosystem type. However, applying these data for complex tasks such as water management and regional planning would create at least two serious problems: 1) the fragmentation of spatial units into nine separate Geographical Information System (GIS) layers and the related disparities between them in the form of gaps and overlaps; 2) the absence of mapping for large parts of the country which makes it impossible to cover with data an entire study area. To solve such issues, it is necessary to develop an approach that enables integrated mapping of ecosystems. Forest ecosystems are the most important providers of various services from each of the main ES groups (provisioning, regulating, cultural) as they ensure valuable functions that support their supply (Acharya et al., 2019; García-Nieto et al., 2013). From this point of view, the mapping of forest ecosystems should have special attention in every study that addresses ES assessment at a national or regional scale.

The first attempt to map the ecosystems in Bulgaria based on MAES typology was made by Nedkov et al. (2017). The authors utilized CORINE Land Cover (CLC) data to delineate and map ecosystems in Bulgaria for four periods between 1990 and 2012 and reveal the dynamics of ecosystems for this period. According to this

study, agricultural (48%) and forest (38%) ecosystems cover the highest part of the country. This study gives a general overview at the national level but for more precise estimation at regional and especially local level, the CLC data is too raw, and more precise data is needed. Hristova, Stoycheva (2021) explores the relationship between the CLC classification and the MAES typology to develop a basis for mapping ecosystems at a national level for the needs of nature heritage assessment. The relationships between CLC classes and MAES ecosystem types and subtypes established in this study provide valuable information for cross-walking with other data sources and the implementation of integrated approaches for mapping ecosystems. According to the methodological framework (Burkhard et al., 2018), the mapping of ecosystems can be compiled and the underlying spatial data can be analyzed using GIS techniques. The mapping procedures are prone to particular uncertainties during the delineation using spatially explicit units. This is valid, especially in cases when integration of various data sources is necessary. This is an important research gap that needs further studies and a search for appropriate methods of data integration. To solve such problems, it is necessary to develop an approach that enables integrated mapping of ecosystems.

The analyses of the ecosystem data produced during the implementation of the national methodology for mapping ecosystems in Bulgaria reveal two main problems that may cause confusion in cases of integrated assessment of all ecosystem types (Petkova et al., 2022). The first one is related to discrepancies between the typologies of the nine ecosystem types and the hierarchical levels in some of them. This necessitates a revision of the typology, which aligns with the recommendations towards better consistency of the mapping efforts (Maes et al., 2020). The second comes from the topology analyses of the merged data from the eight ecosystem GIS layers (the ninth is about marine ecosystems which are not presented in the study area) which show huge numbers of gaps and overlaps. This determines the development of a new approach for mapping all ecosystem types into a uniform database (Petkova et al., 2022).

The main objective of this study is to present an approach that enables formulation of a uniform spatial dataset based on the mapping of the main ecosystem types, that can be used for mapping of ES at a river basin scale. It has been applied to the upper part of the Ogosta River basin and the result is a topologically correct uniform spatial data layer.

Materials and methods

Case study area

The upper part of the Ogosta River basin (Fig. 1) is chosen as a case study to test the proposed approach. This area has been an object of various studies which ensures data availability and options for validation. The Ogosta River starts from a spring under Vrazha Glava peak (1935 m) in the Chiprovska mountain at about 1760 m. Next to the village of Belimel, it flows in a north-easterly direction in a narrow valley. After the

merge with its left tributary, the Prevalska River, it turns to the southeast and forms a wide valley, occupied mainly by arable land. This part receives the biggest tributary—the river Dulgodelska Ogosta. Further downstream it enters the second largest dam in Bulgaria, the Ogosta Dam.

The topography is mainly mountainous with the highest point being Golema Chuka (1967.2 m). From north to south, it goes from low-mountainous in the region of Black Peak (1017.5 m) and the valley of the Ogosta River, to medium and high-mountainous. The climate is temperate continental with distinct mountain features in the southern part of the basin. The average January temperatures are between 0 and 1.5°C, and in the mountains, it reaches -9°C. The average July temperature is between 22 and 24°C, decreasing to 10-11°C in altitude. The average annual precipitation varies between 500 and 650 mm in the low mountain part and increases to 1000 mm in the high mountain part.

The anthropogenic impact in the study area has various aspects. The most pronounced in the spatial aspect are the land use changes but in the environmental quality aspect are the problems form the former mining activities that cause heavy metal pollution in the water and floodplains along the Ogosta River (Kotsev, Stoyanova, 2022; Marcheva et al., 2023).

Spatial data sources

The analyses of the ecosystem data produced during the implementation of the national methodology for mapping ecosystems in Bulgaria reveal that it is impossible to integrate the spatial units from the different ecosystem types into a uniform topologically correct GIS layer (Petkova et al., 2022). This is mainly due to the differences in the data sources used to build the geometry of the spatial units that represent the ecosystem types. Therefore, it is necessary to build the ecosystem dataset starting with a uniform GIS layer that can be used as a spatial framework for further development of the dataset. This spatial data source should fulfill the following criteria: (i) to cover the whole territory of the country; (ii) to have a classification that can be appropriately translated to the MAES typology; (iii) to have a resolution that corresponds to the requirements of the national methodology for mapping of ecosystems in Bulgaria; (iv) to have appropriate precision for mapping of ecosystems at a national scale. Four spatial datasets cover the whole range of ecosystems in Bulgaria: 1) the national dataset produced from the mapping of ecosystems in Bulgaria under MAES methodology (MAES BG); 2) CLC dataset; 3) the European Space Agency (ESA) world cover; 4) the physical blocks (PB) dataset. The spatial extent of the ecosystems derived from these sources is presented in Fig. 2. Furthermore, there are sectoral datasets that have no full coverage of the country and contain data on one or two ecosystem types.

The MAES BG dataset is planned to have full coverage at a national scale following the methodological framework that contains nine separate methodologies. Each of them covers one of the nine main ecosystem types according to the MAES typology. This led to the development of nine separate databases generated within seven

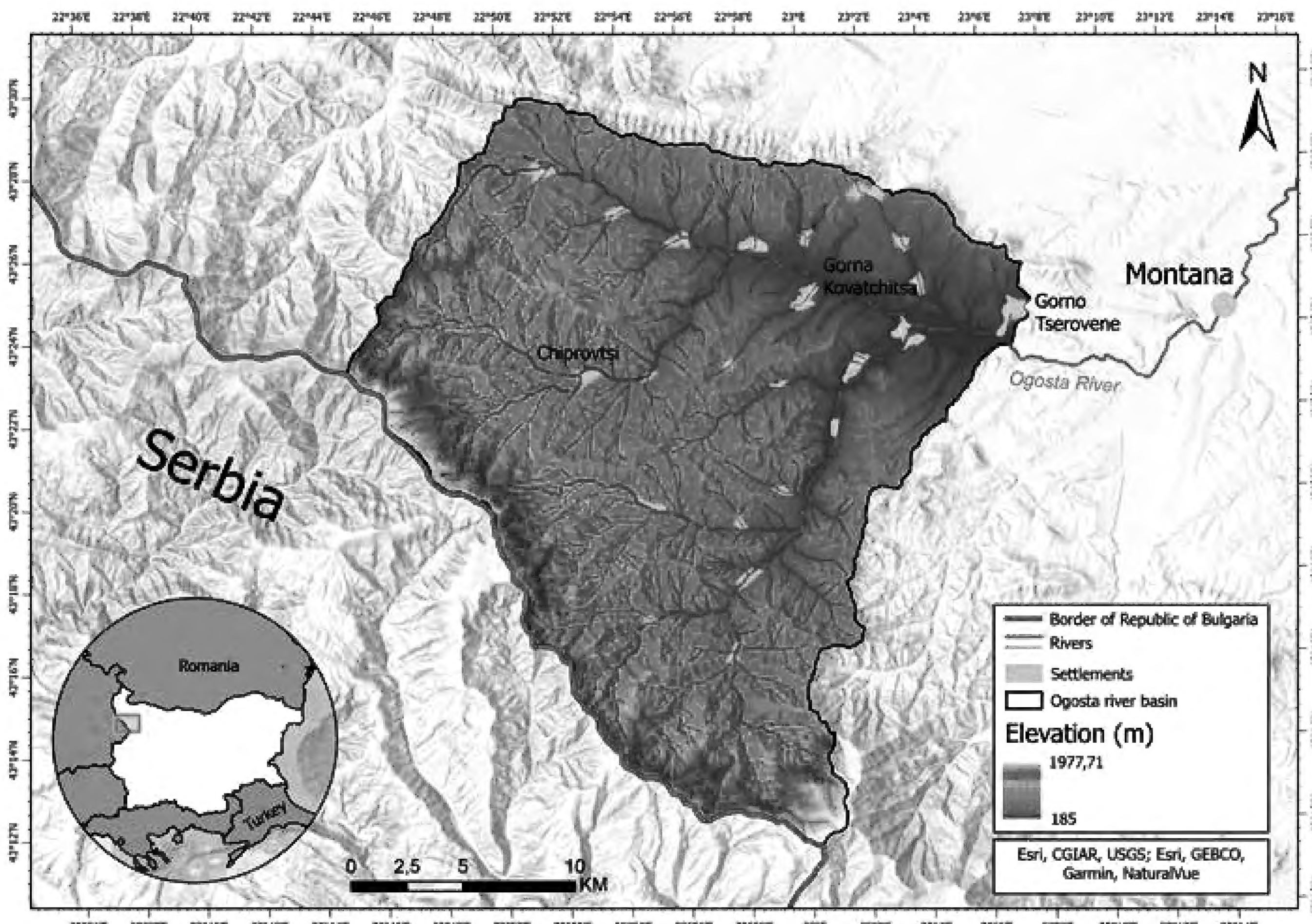

Figure 1. Case study area of the upper part of Ogosta River basin

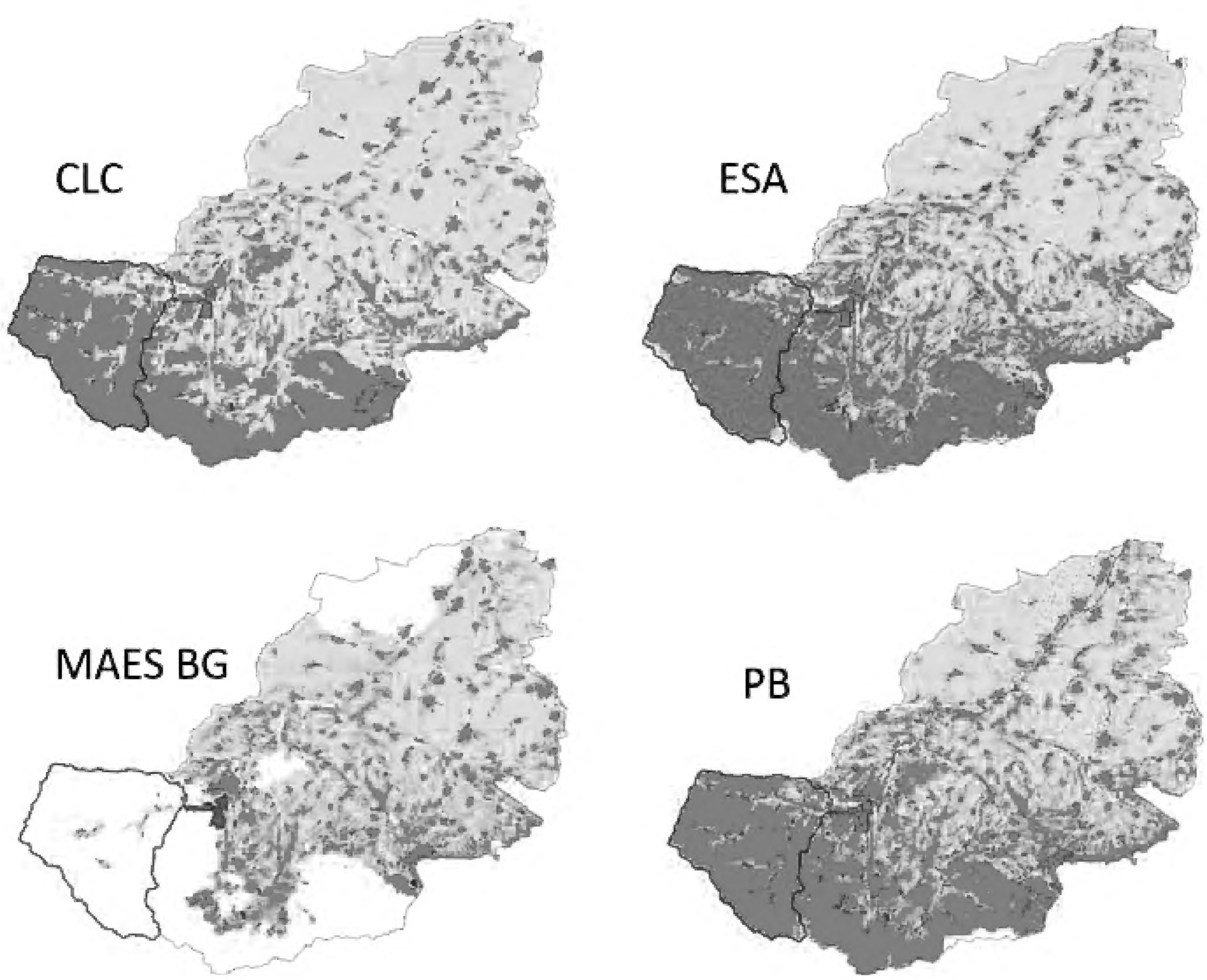

Figure 2. Spatial data sources in the Ogosta River basin

projects funded under the program BG03 "Biological diversity and ecosystem services" of the European Environment Agency grants. However, the mapping results now cover about 65% of the territory of the country. Therefore, this database is not suitable as a basis for integrated mapping as it does not yet have national coverage. The second reason is related to the gaps and overlaps analysis results presented above, which show that they are practically unfit for integration due to topological incompatibility. Nevertheless, this database could be used in the analysis to establish consistency with other sources and to quantify their mapping.

CLC as a spatial data product offers a pan-European land cover and land use inventory with 44 thematic classes, ranging from broad forested areas to individual vineyards. It is updated with new status and changes layers every six years (Bossard et al., 2022). CLC is directed to a multitude of users and has nearly limitless potential and actual applications in fields such as environmental assessment, land use change analyses, climate change assessments, etc. The main objectives of the program are: 1) collection of information about the environment concerning individual aspects that have priority for all member countries; 2) coordination of data collection and organization of information between member countries and/or internationally; 3) ensuring consistency of information and compatibility of data. The scale is 1:100 000 and the minimum mappable unit is 25 ha. The nomenclature is organized into three levels. The first level has 5 classes covering separate categories that are abstract to one degree or another of the land cover. The second level has 15 classes that are scaled from 1:500,000 to 1:1,000,000. The third level has 44 classes which represent the CLC project at a scale of 1:100,000.

The ESA initiated the World Cover project. The ESA World cover product data was developed in response to the need for accurate, timely, high-resolution information on land use/land cover and its changes. The key output of this project was the release in October 2021 of a freely available 10 m resolution global land cover product for 2020, based on both Sentinel-1 and Sentinel-2 data, containing 11 land cover classes and independently validated with a global overall accuracy of 74.4% (Zanaga et al., 2021). Its development further builds on the experience of Glob Cover and CCI Land Cover by the European Space Agency (Arino et al., 2008; ESA, 2017). The algorithm used to generate the ESA World Cover product is based on the 100 m resolution Copernican Global Land Cover (CGLS-LC) dynamic annual land cover algorithm (Buchhorn et al., 2020). The CGLS-LC workflow used 100 m, 5-day, Proba-V data as input, which were reprocessed on the Sentinel-2 UTM grid together with training data obtained at 10 m resolution.

The PB database was developed by the Ministry of Agriculture and Food (of Bulgaria) based on remote sensing data and the creation of an orthophoto map. Land cover is classified into nine types, each of which is differentiated into subtypes depending on land use. The nine types are: arable lands, forest areas, urban areas, water areas and wetlands, disturbed areas, transport infrastructure, bare and eroded areas, other areas, and areas with other uses.

Quality assessment of the spatial data sources and development of a spatial framework for mapping of ecosystems in the case study area

Following the above-mentioned criteria, we assessed the four datasets. The MAES BG dataset failed at the first criterion as it does not have full coverage of the country. The other three datasets passed this criterion as well as the second (about the classification) and the third (about the resolution). The fourth criterion (precision) needs a more comprehensive approach. Thus, we developed an approach for data validation of the spatial data sources to define their precision and furthermore - to choose the most appropriate dataset to be used as a spatial framework. It is based on control points for validation of the mapped data in the individual sources. Validation is done in two ways: visual interpretation by orthophoto map and field validation. Visual interpretation on an orthophoto map is done for all control points. Field validation requires significantly more travel time and funding, so it is done for selected points where the visual interpretation is assessed with low confidence. For this purpose, a two-level confidence scale has been introduced in this type of check—high and low. The first is introduced when the type (or subtype) of the ecosystem is very clearly visible on the orthophoto map and the visual interpretation is considered reliable. The second is introduced when the type of ecosystem cannot be unambiguously determined or there are doubts about the type of vegetation. Validation points were randomly determined by forming a grid of points in GIS using the Fishnet function. The points are arranged in a regular grid with a distance between the points of 250 m.

The results of the assessment show that the PB dataset has the highest precision and it was chosen as a spatial framework for the mapping of ecosystems. The process of building the spatial framework contains two main stages. In the first stage, the PB classification was correlated to the MAES BG classification. In the second stage, the PB classes in the attribute table of the PB GIS layer were transformed into ecosystem types and subtypes following theMAES BG classification. The resulting GIS layer has the geometry of the PB dataset and the classification of MAES BG.

An approach for data integration of forest and urban ecosystems

The spatial framework based on PB data meets the requirements about national coverage, relation to the MAES typology, and resolution of the data. However, the fourth requirement about the appropriate precision is not fully covered as the data for some ecosystems is not detailed enough to represent their spatial distribution at the scale and precision at level 3 of the MAES BG typology. For instance, the forests in PB are presented in a single class which makes it impossible to distinguish the forest ecosystem subtypes (level 3 of MAES BG). PB's urban ecosystems have several classes corresponding to ecosystem subtypes, but the comparison with the MAES BG urban database shows particular differences. The latter is more detailed and precise in the mapping of urban subtypes. Therefore, the ecosystems at level 3 and 4 should be updated. However, such an update should keep the topological quality of the dataset

which necessitates the development of precise procedures for the update of the ecosystem subtypes.

The algorithm that contains the spatial procedures for the update of the forest and urban ecosystems in the case study area is presented in Fig. 3. The initial GIS layer developed from the PB dataset (ogosta_eco_mzh) is used as a spatial framework to integrate the forest and urban ecosystem data. The forest inventory dataset is used as a source for forest ecosystem updates. This dataset contains detailed data about various forest parameters developed for the regional and local forestry plans. The first two steps of the procedure (the green part of Fig. 2) are applied to correlate the categories from forest inventory data (Dleso_ogosta and woods_upper_ogosta_basin) with the ecosystems typology and intersect the polygons from the two datasets. The spatial units from the datasets do not fit each other perfectly, causing the formation of many small polygons that should be removed (step 3). The next two steps include procedures to verify the results of the intersections and prepare separate layers with the updated forest ecosystems at level 3 of the MAES BG typology. Then the data from this layer is integrated into the spatial framework differently due to the specifics of the datasets.

Mapping of ecosystems and the services they provide

ES maps quantify and visualize where and to what extent ecosystems contribute to human well-being (Burkhard, Maes, 2017). To test the applicability of the developed ecosystems database, we applied the matrix approach (Burkhard et al., 2012) for ES mapping to four water-related ES (flood regulation, erosion control, water quality regulation, and local climate regulation). To represent ES in a spatial context, it is necessary to define where ES are generated i.e., to map ES supply. In the context of the

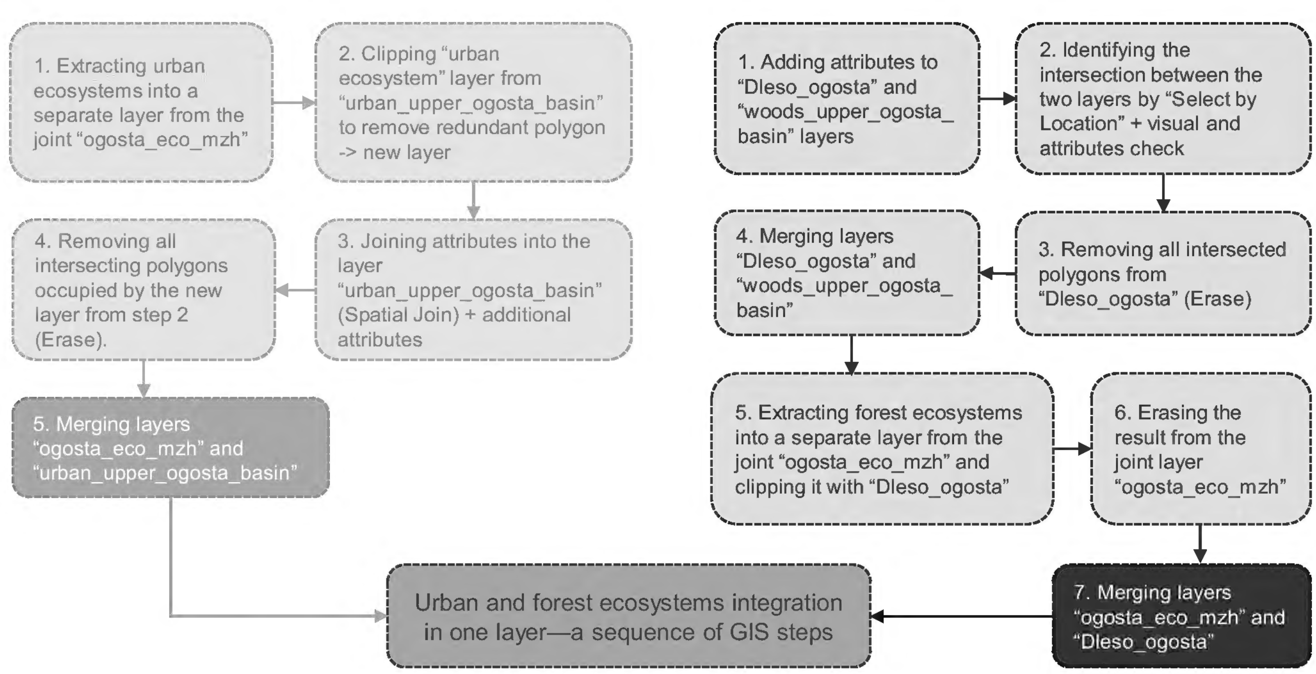

Figure 3. An algorithm of spatial procedures for data integration of the forest and urban ecosystems

mapping and assessment framework, it is important to clarify the place of the spatial units outlined during the phase of ecosystem mapping. In our case, we use the ecosystems as the spatial units that provide the ES. The capacities of the identified spatial units were assessed on a relative scale ranging from 0 to 5 (after Burkhard et al., 2009, 2012). A 0-value indicates that there is no relevant capacity to supply flood regulating services and a 5-value indicates the highest relevant capacity for the supply of these services in the case study region. Values of 2, 3, and 4 represent respective intermediate supply capacities.

Results

Ecosystems in the Ogosta River basin

The mapping of ecosystems is a process that involves various activities in spatial data gathering, data processing, and data storage. The main result of these processes is the generation of a GIS database for the ecosystems. The application of the proposed approach enabled us to develop a GIS database for the ecosystems in the upper part of the Ogosta River basin. It contains spatial data for seven ecosystem types presented in the study area. Only marine and wetland ecosystems are not presented in the study area. The dataset contains 16598 polygons with an average size of 4.25 ha. The map of ecosystem types (Fig. 4) represents their spatial distribution in the study area. The Woodland and forest ecosystems cover by far the largest part of the area with about

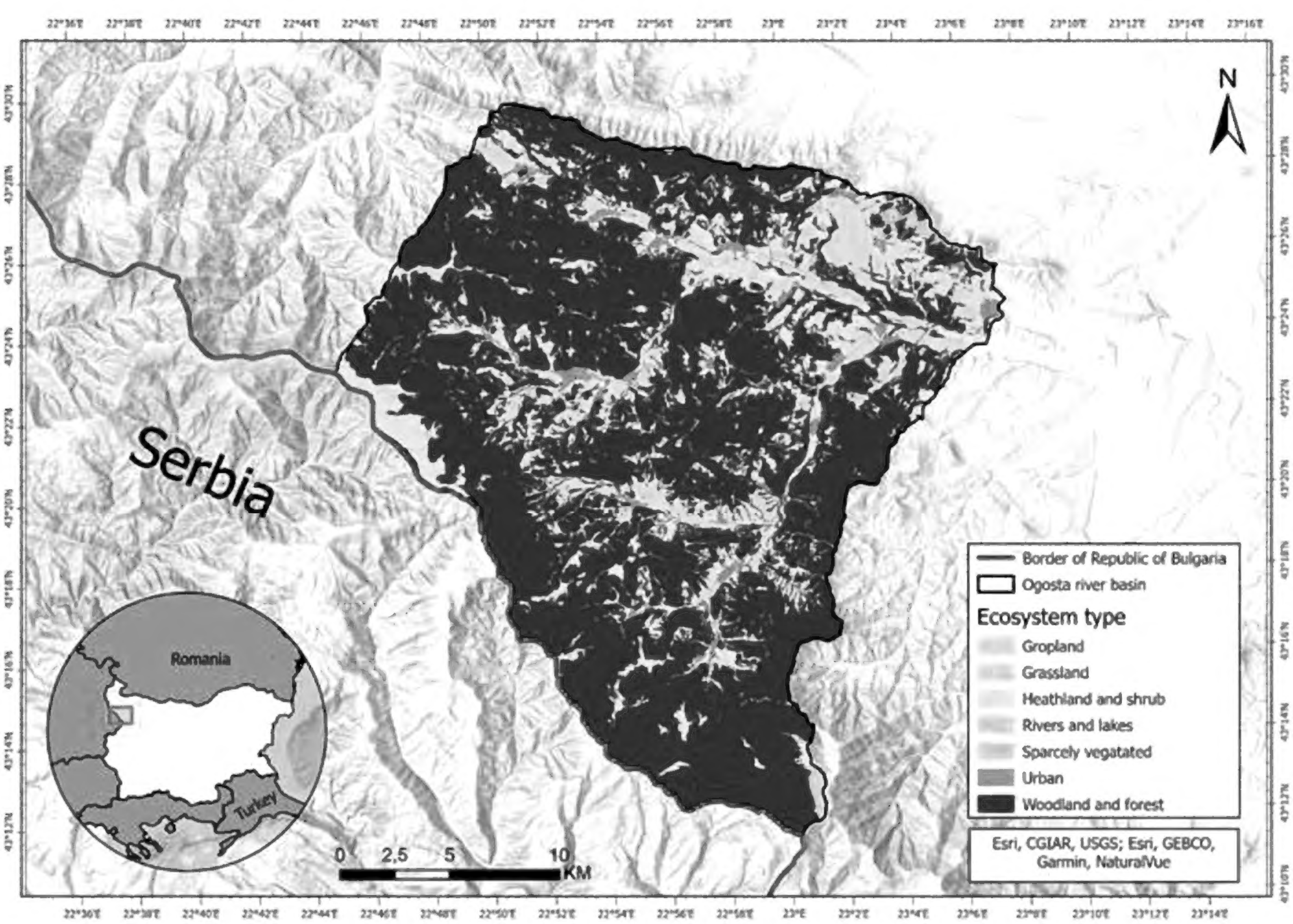

Figure 4. Ecosystems in Ogosta River basin

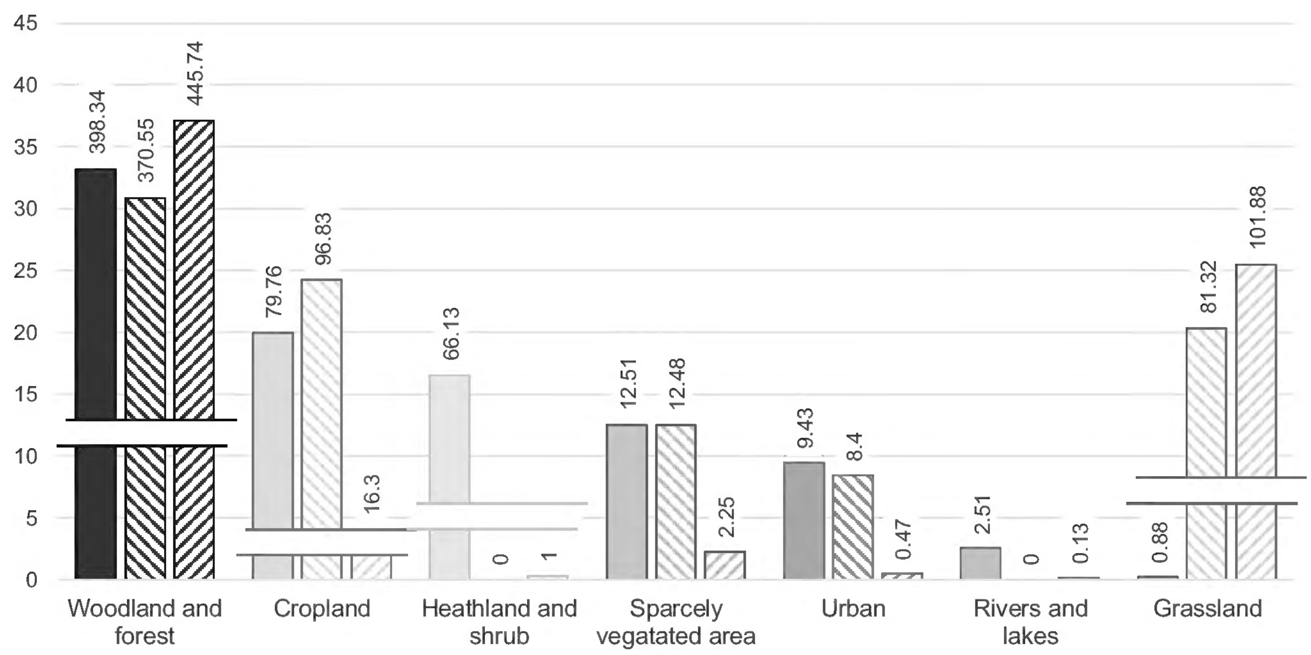

Figure 5. Spatial distribution of the ecosystems in Ogosta River basin

70% share of the whole basin. Cropland (13.5%) and Heathland and shrub (11.6%) are also well represented and with the forests, they comprise almost 96% of the study area. The croplands are presented mainly in the northeastern part of the area, while the shrubs are distributed evenly around the basin. The Urban ecosystems cover about 2.1% located mainly along the river valleys throughout the basin. The Rivers and lakes (0.4%), Sparsely vegetated (1.6%) and Grasslands ecosystems (0.2%) have limited extent in the basin.

The comparison of the results about the ecosystem distribution from the application of the proposed approach, and two of the other sources of spatial data show some similarities but also pronounced differences (Fig. 5). The area of the Woodland and forest ecosystems vary from 370.55 km^2 (according to CLC data) to 445.74 km^2 (ESA) with the results from our mapping placed in between them with 398.34 km^2. The most pronounced are the differences in the Heathland and shrub ecosystems with 66.13 km^2 from our mapping quite limited from the other two sources. The results for Cropland ecosystems are similar between our mapping (mainly based on the PB dataset) and CLC data. In contrast, the area from ESA data is almost four times lower. The results for Grasslands ecosystems show a similar pattern but, in this case, CLC and ESA data show close results, while the ecosystem types based on PB data are almost absent in the study area.

Forest ecosystems in the Ogosta River basin

The distribution of forest ecosystems as the most important type in the study area should be analyzed in more detail (Fig. 6). According to the MAES BG typology at level 3, there are four ecosystem classes that correspond to the ecosystem subtype. These are Coppice forests, High deciduous forests, Coniferous forests, and Mixed forests. The application of the proposed approach enables the combination of PB and

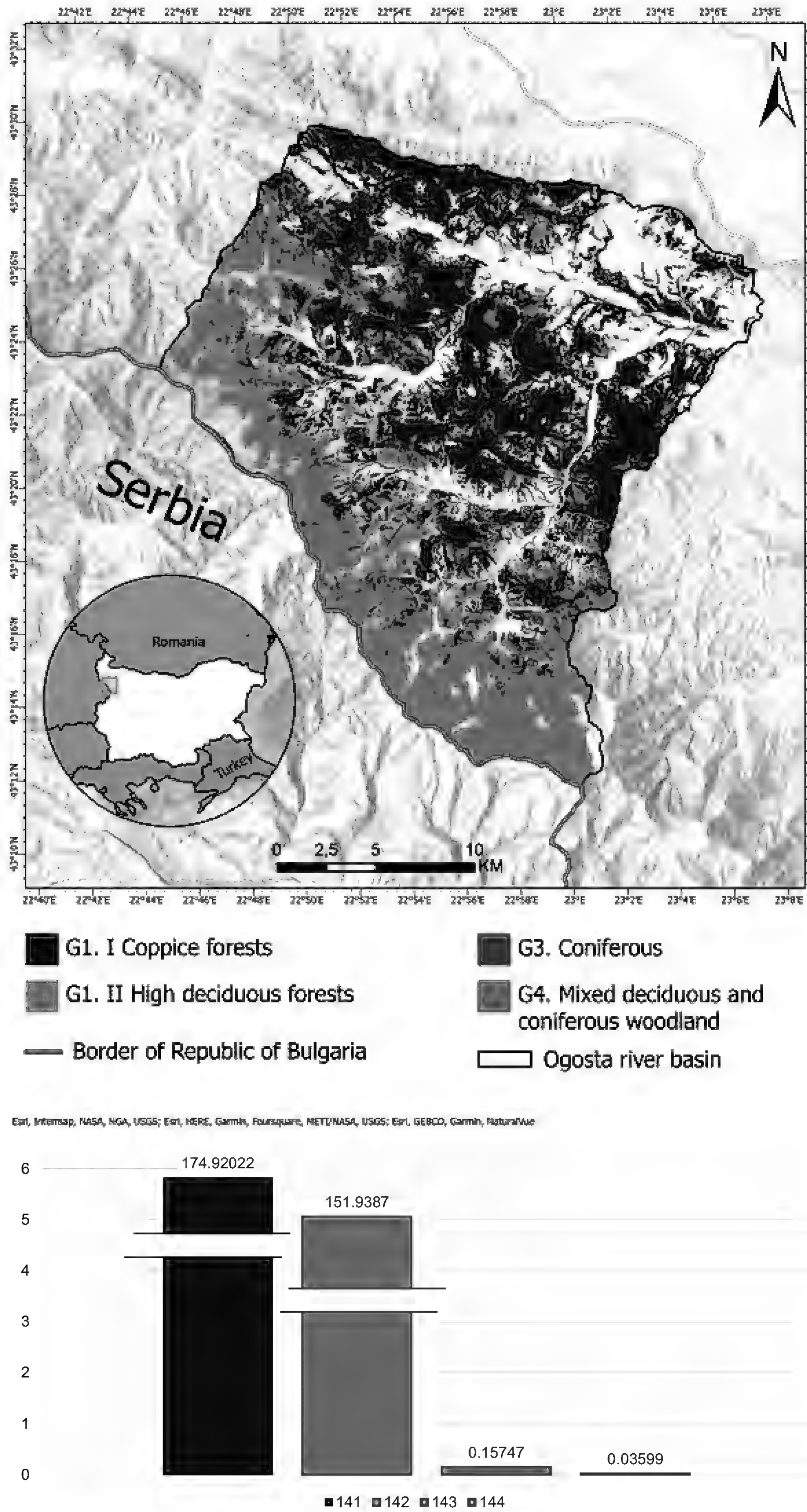

Figure 6. Forest ecosystem subtypes in Ogosta River basin. 141–Coppice forests; 142–High deciduous forests; 143–Coniferous forests; 144–Mixed forests

forest inventory datasets which in this way complement each other. The results show a pronounced predominance of the deciduous forest covering 99.9% of the study area. The coppice forest has a slightly higher extent with 174.9 km^2 (53.5%). They are located in the northern part of the basin at a lower altitude. The high deciduous forests cover 151.9 km^2 (46.4%) of the basin, located mainly in the southern more mountainous part. The coniferous and mixed forests have a limited extent as small patches in the southern part of the basin.

Selected ecosystem services in Ogosta River basin and the role of the forest ecosystems

The main objective of ecosystem mapping is to define the spatial pattern of the ecosystem types which is a basis for further mapping and assessment of the ES. To test the applicability of the ecosystems database for mapping ES, we choose four water-related ES: flood regulation, erosion control, water quality regulation, and local climate regulation. The supply capacity of the ecosystems was estimated using the scores for respective services from the MAES BG database. As the mapping of ecosystems in the upper part of the Ogosta River basin has a limited extent, we extracted the scores from the mapping of the whole basin (Fig. 2). The scores of the four ES per ecosystem type for the whole basin were transferred to the ecosystems in the case study area. The resulting maps are presented in Fig. 7. The maps show that the ecosystem in the upper Ogosta River basin has a relatively high capacity for all four selected ES. The forest ecosystems have the main role for such a high score. Specifically, the High deciduous forests subtype has the most important contribution to these results. The areas with very high capacity (score 5) for flood regulation and erosion regulation almost entirely overlap with the distribution of high deciduous forests. For water quality regulation they have high capacity (score 4) but again these are the areas with higher scores than the rest of the area of the basin. The map of capacity for local climate regulation shows a slightly different pattern as both High deciduous forests and Coppice forests have very high capacity.

Discussion

The proposed approach for integrated mapping of ecosystems enables the combination of information from different spatial data sources in a topologically correct vector layer using an algorithm of consecutive GIS techniques. The main advantage of the approach is the opportunity to integrate all nine ecosystem types into a single dataset that can be used for ecosystem services modeling and assessment designed for specific practical activities such as water management at the river basin scale, flood risk assessment, spatial planning, etc. The results for the upper part of the Ogosta River basin confirm its applicability and demonstrate that this is a significant upgrade to the mapping of ecosystems based on the CLC data (Nedkov et al., 2017). The main limitation is that it uses one particular spatial data source as a spatial framework

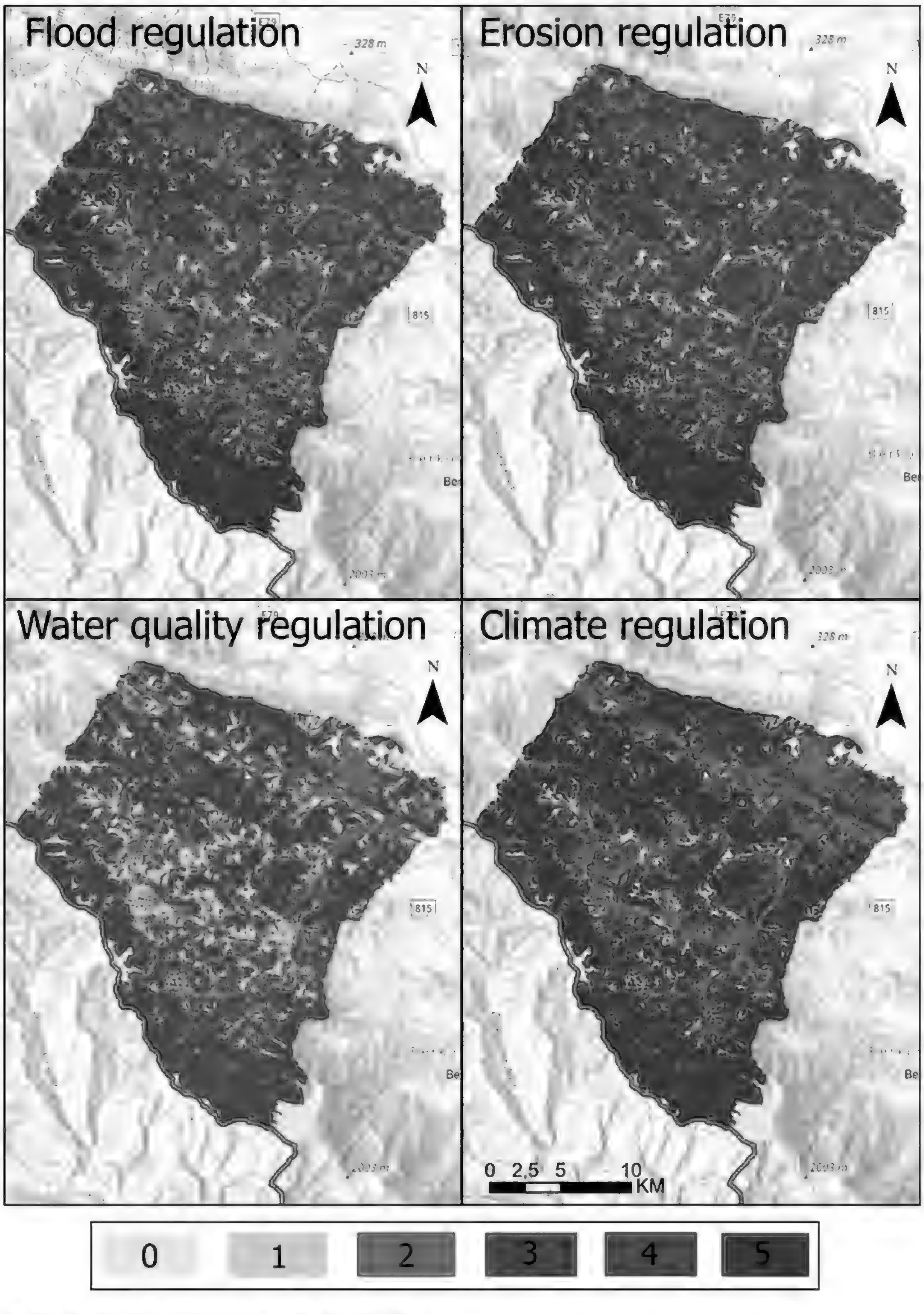

Figure 7. Selected ecosystem services in Ogosta river basin, ES capacity classes: 0–no capacity; 1–very low capacity; 2–low capacity; 3–moderate capacity; 4–high capacity; 5–very high capacity

which means that the limitations of this dataset would be transferred to the resulting ecosystem mapping. Thus, the main challenge for the development of the approach is to find appropriate methods for the comparison of different spatial data sources and update the ecosystems delineation which can increase the precision of the results. In the current stage, the approach has well-developed algorithms for the integration of forest and urban ecosystems. The agricultural ecosystems are well represented in the initial PB dataset but the delineation and the spatial representation of the other ecosystems should be evaluated and the most appropriate data sources for update need to be found.

The differences in the spatial coverage of the ecosystems between the results from our test mapping in the case study area and the other spatial data sources (specifically ESA and CLC) are indicators for uncertainty that need further research. The variations in the spatial extent of the forests are caused mainly by the different initial data sources and the methods for their interpretation. The ESA world cover uses Sentinel data and automated classification of the satellite images. It also has no minimum mapped units (in contrast to CLC) and could not distinguish between forest and shrub vegetation. All these factors led to higher forest cover than any other sources. The forest inventory data also has lower values for the forest cover which is due to the limitation of the inventory within the administratively defined forest lands. Therefore, some forest areas outside these borders are not counted. For instance, there are abandoned agricultural lands that were recovered to forests during the last 20-30 years but they are still not included in the lands that are managed by the forestry agency. The PB dataset appears as the most precise source to outline the forested areas as it is developed from high resolution aerial photographs and visual interpretation. The problem with this dataset is the lack of differentiation of the forest types.

The differences in the Heathland and shrub ecosystems are mainly due to classification discrepancies. The results for Cropland ecosystems show similar results between our mapping (mainly based on the PB dataset) and CLC data. In contrast, the area from ESA data is almost four times lower. The results for Grasslands ecosystems show a similar pattern but, in this case, CLC and ESA data show close results, while the ecosystem types based on PB show that these ecosystems are almost absent in the study area. Further validation and update of the shrubland and grasslands data is much needed and the other studies on grassland vegetation such as Grigorov et al. (2021) could be helpful.

Applying the proposed approach enables the improvement of information about the forest ecosystem by combining the PB and forest inventory data as they complement each other. The outline of the PB better reflects the current state as it incorporates all forested areas. The differentiation of the forest types is ensured by the forest inventory data. The results about the limited extent of the coniferous and mixed forests have different explanations. The coniferous forests are not typical for Stara Planina Mountain in general and the study area is no exception. However, the results for mixed forests need further checks and potential updates because the CLC data show a higher extent of such forests. The reason for such a difference is the variety of

methods used in CLC and forest inventory. Further development of the approach towards the delineation of the forest's ecosystems at the fourth level of the MAES BG typology is much needed. The data from forest inventory contains such information but its format does not allow direct link with the columns in the attribute table. Solving this problem will also contribute to the above-mentioned case with the mixed forests.

The results of the test mapping with four water-related ES (flood regulation, erosion control, water quality regulation, and local climate regulation) are encouraging as they show a good correlation with other studies on these ES (Boyanova et al., 2014, 2016; Nikolov et al., 2022;). The ecosystems database is an appropriate source for mapping ES at tier 1 (Grêt-Regamey et al., 2015) but also as an input for ES models that can generate more comprehensive and precise results for the spatial distribution of these services.

Conclusion

The approach for integrated mapping of ecosystems, presented in this paper, gives one possible solution to problems related to the different sources of information and the discrepancies between ecosystem types in the national mapping of ecosystems in Bulgaria. It is based on the use of a uniform spatial framework that outlines the ecosystem types and sets the initial database for further mapping. This ensures a topologically correct spatial dataset for the ecosystems and a background for further updates for each ecosystem at the different levels of MAES typology. Research shows that the most appropriate spatial basis for the territory of Bulgaria is the database for the physical blocks of the Ministry of Interior (Nedkov et al., 2023). Its application to the studied river basin gives encouraging results and can be used as an example for similar areas. Further development of the approach will ensure mapping of the forest ecosystems at level 3 of the MAES BG typology and more precise delineation of the grassland, heathland, freshwater, and sparsely vegetated ecosystems.

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